NOTES de RECHERCHES

GLACIOLOGICAL CONDITIONS AND
GEOMORPHOLOGICAL INTERPRETATION

by

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RESEARCH NOTES

Department of GEOGRAPHY

Département de GÉOGRAPHIE

UNIVERSITE d'OTTAWA UNIVERSITY of OTTAWA

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GLACIOLOGICAL CONDITIONS AND GEOMORPHOLOGICAL INTERPRETATION.

ABSTRACT.

The paper draws on examples from the Pennines of northern England and the St.Elias and Ruby Ranges of the southwest Yukon to demonstrate the importance of the construction of a glaciological model before interpreting glacial geomorphological history.

INTRODUCTION

The geomorphological record of the action of glacier ice during the Pleistocene and the Holocene is a combination, in both the deposits and their morphology, of the changes which occurred over time in the ice mass. Quaternary geomorphological and geological interpretations must initially be glaciologically sound if the hypotheses are to be useful in promoting fundamental research rather than continually modifying existing concepts. Glaciology has, in the course of the last three decades, arrived at an understanding of the physics of ice movement sufficient to apply to geomorphological problems although there are many aspects of ice deformation which remain highly theoretical and are difficult to apply.

That North America, Europe and Scandinavia were dominated by ice throughout the Pleistocene is totally accepted but the question of the physical conditions of the ice remains. The validity of using models constructed for the present Greenland and Antarctic ice sheets to predict the nature of the Laurentide Ice Sheet is questionable. Did the ice even have the same physical and chemical properties as present day ice? Koerner and Fisher have found that the basal ice in cores of the Arctic ice caps, which they hypothesise as being late Pleistocene ice, has very different physical and chemical properties from the overlying Holocene ice.

For the Laurentide Ice Sheet we have, over the last one hundred years, gone from hypotheses of one centre of ice dispersal to three centres (Tyrell, 1913), to one centre (Flint, 1943) and back up to four or five centres (see discussion Ives et al., 1975). The glaciological implications of these hypotheses are not fully comprehended and perhaps the arguments about the number of ice domes or centres of dispersal are irrelevant, serving only to encompass newly emerging geomorphological detail, and that a model of constantly changing ice conditions in response to climatic change would be more appropriate. The necessity to hypothesise domes of dispersal stems from the assumption of similar responses throughout the ice sheet and perhaps can be traced back to the old ideas of four fold succession of ice ages Nebraskan, Kansan, Illinoian and Wisconsin) and the maintenance of the term

'Wisconsinan' for a last major period of ice advance. Responses of the ice sheet occur as the accumulation and ablation patterns vary producing a multiplicity of ice flow changes, of which, only the final phases will be preserved in the landforms and a composite in the dispersion of trace elements in the deposits.

The latest model of the Wisconsin Ice Sheet (Dyke, Dredge and Vincent, 1982) serves as an example of the geomorphological approach. This is a multi dome model with conclusions based on ice dome profiles calculated from a theoretical model developed for the Greenland and Antarctic Ice Sheets. In these two locations the glaciological and basal morphological conditions are very different from those of the Laurentide Ice Sheet which covered the lowland area of the Hudsons Bay basin. Among the glaciological questions which arise from the paper are; why does the radical flow pattern indicated by the geomorphology equate with similar size and symmetry of ice domes? (pg. 7); what are large basal ice streams? (pg. 7) that are hypothesised as being responsible for the dispersal trains?; and what are the climatic explanations for the multi dome configuration? Intensive modelling work has been done on the nature of the atmospheric circulation during the Pleistocene but can it account for the development of a number of major, persistent, ice domes on the ice sheet?

An example of glaciological implications in the mountain environment is the surging glacier phenomena in the St. Elias Mountains of the southwest Yukon and Alaska. The frequency of glaciers which exhibit this phenomena means that surging and non-surging glaciers occur in adjacent valleys throughout the region.

The mechanisms of glacier surging are still only tentatively understood but because surging affects a significant proportion of the present valley glaciers it is reasonable to assume that the phenomena occurred in a number of glaciers in pre-recent time. Very little discussion has emerged on the geomorphological implications of this phenomena. In the St. Elias Mountains Rutter (1969) has examined differences between moraines produced

by surging and non-surging glaciers, the Klutlan glacier has been studied very extensively (Driscoll, 1980; Rampton, 1969; Watson, 1980; Wright, 1980) and the author (Johnson, 1972) has studied the effects of surging on the ice cored moraine systems of the Donjek Glacier. The occurrence or non-occurrence of surges has been shown to have a controlling influence on many aspects of the evolution of the glacial environment and makes the drawing of comparisons between neighbouring valleys most difficult.

BACKGROUND TO THE PAPER

This question of glaciological implications of interpretations first arose to the author during field work in the central Pennine Range of northern England. Ice flow has for a long time been documented as a regional flow north to south down the geologically controlled lowland of the Vale of Yorl. This ice flow pushed up the foothills of the Pennines where it crossed the east west oriented valleys, that is across the morphological "grain" of the country. The valleys are deeply incised into the magnesian limestone and millstone grit bedrock and the geomorphological evolution was controlled by the ice flow across them and the glaciological conditions induced in them. All of the rivers have been diverted and large glacial and fluvio-glacial debris plugs occur in the old valley courses with only minor ice marginal landforms on the interfluves. Glaciological implications have however never been discussed in the course of geomorphological interpretation of the area.

This paper discussed the importance of the glaciological conditions in the interpretation of the Pennines, the Kluane and Donjek Ranges in the St. Elias area and the Ruby Range to the east of Kluane Lake in Yukon. It proposes that glaciological interpretations are more important than geomorphological interpretations in understanding the evolution of landscape.

GLACIOLOGY OF THE PENNINE CASE

The morphology of the eastern slope of the Pennines in central Yorkshire reflects the geological base with the upland areas underlain by the

Carboniferous Millstone Grit and Permian Magnesian Limestone and the lowland Vale of York by the softer Triassic Sandstones (Fig. 1). With regional ice moving south down the Vale of York the basal morphology of the ice changed from the low elevation range, undulating surface of the Vale to the dissected Pennine flank. The stress patterns in the ice would change with the bed elevation change and due to the enforced flow of the ice across the valleys. The nature of the ice flow across the valleys can be hypothesised as either i) the stresses in the ice between the tops of the valley sides would be sufficient to cause shear across the valley leaving stagnant ice in the valley itself, ii) the high stress regimes in the ice between the valley summits would induce deformation in the ice in the valley or iii) the ice would continue to flow through the cross section of the valley (Fig. 2). The location is close to the ice margin and the ice would be thinning up the Pennine flanks and ice conditions across the valleys would therefore be changing progressively.

Within the valleys there are large accumulations of fluvioglacial gravels which have no form but which resulted in major diversions of all the rivers. The problem was initially approached from a simple map analysis technique identifying the elements of the streams which were discordant to the general pattern of drainage. Once the discordant elements of the drainage had been identified and assuming that in diversion had taken place hypotheses were formed as to the preglacial courses. The hypothesised courses were then surveyed using an electrical resistivity traversing technique to determine i) if a buried valley existed and ii) what was the orientation of such a valley. A number of buried valley sections were mapped (Fig. 1) enabling a reconstruction of the preglacial drainage pattern. The cause of the diversions were the glaciological conditions which developed over the valleys. Of the three models of flow across the valleys (Fig. 2, No. i) would be most valid for the deeply incised valleys with the absence of glacial smoothing high on the valley walls, particularly on the downflow side. In the less deeply incised valleys (Fig. 2, No. iii) would be predominant. The stresses within the ice would be such that a major morphological impact might be expected. Differential movement of the ice in the valley (Fig. 2, No. ii) would be possible but no geomorphological evidence was present for this

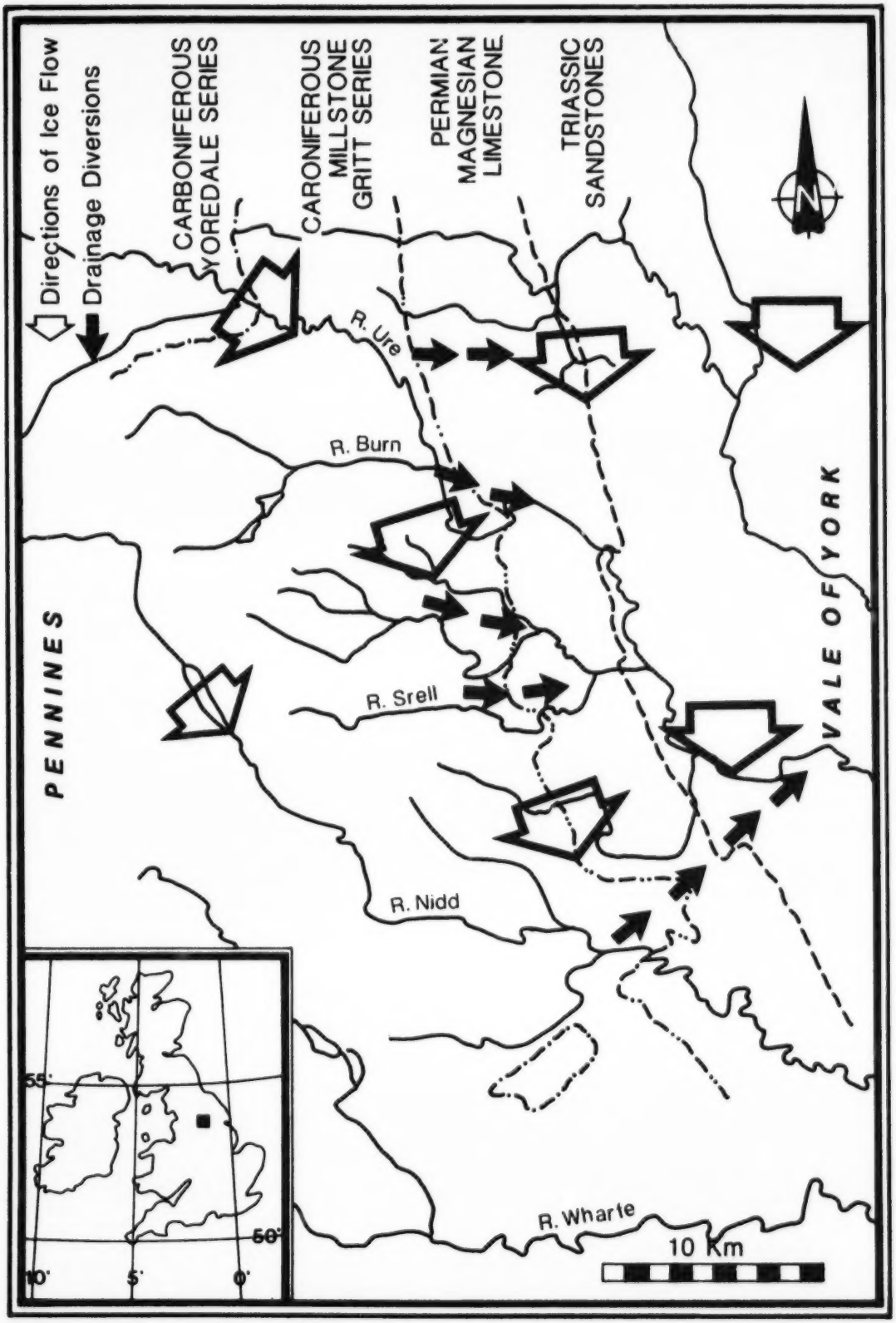
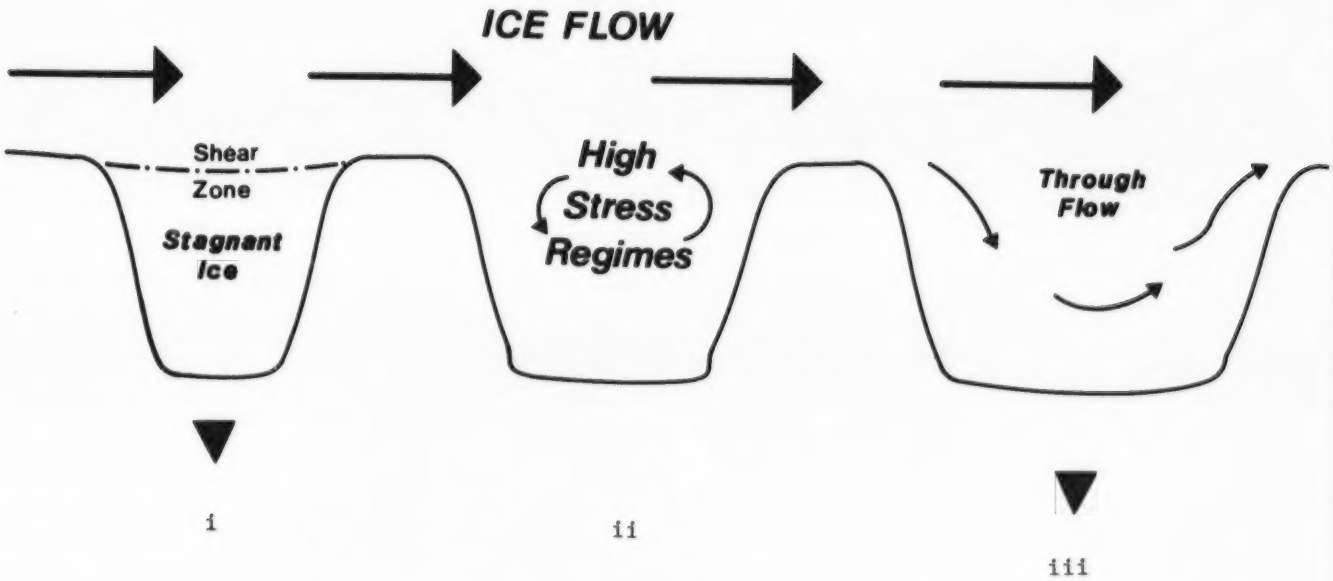


FIG.1. Geological base, ice flow directions and drainage diversions of the Vale of York, northern England.



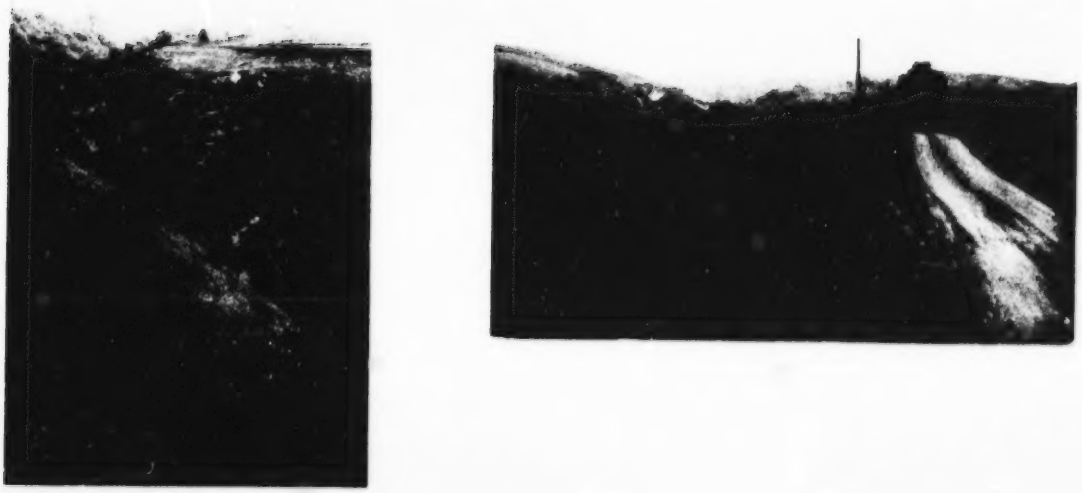


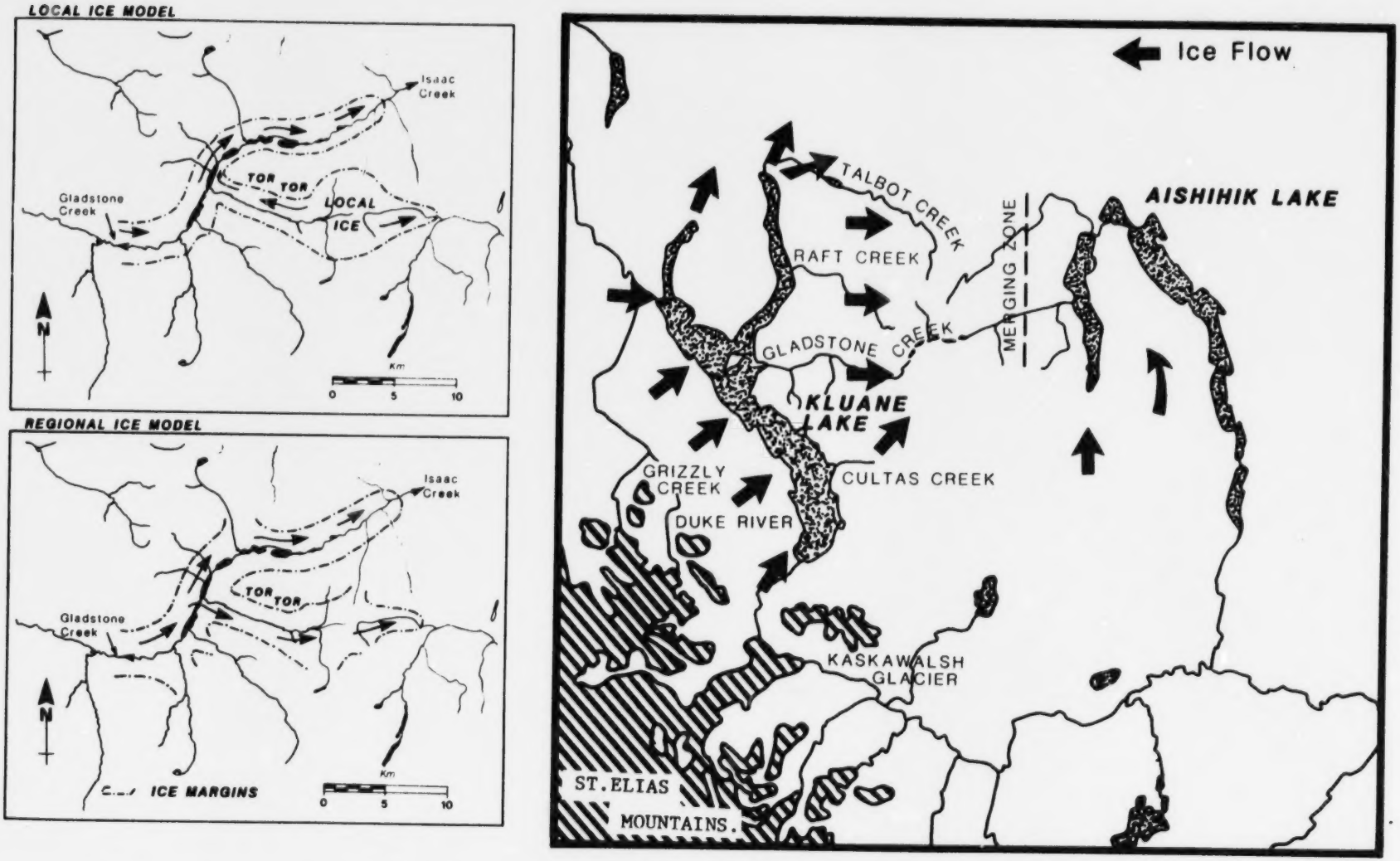
FIG.2. Models of ice flow across valleys with examples from the flanks of the Pennines, Vale of York, northern England.

movement and there would also be a barrier to the movement of subglacially draining meltwater. There is abundant evidence in the valleys for meltwater drainage (Fig. 2, No. i) provides the potential for large amounts of subglacial drainage and accumulation of fluvioglacial deposits which could account for the morphological and stratigraphical evidence of large depositional blockages in the valleys. Only minor meltwater channels exist on the interfluves, except for the components of the major diversions through the interfluves, and most of the meltwater production drained eastward subglacially. With the pre-existing valleys being plugged with deposits new courses were carved through the area. The glaciological conditions which prevailed make it impossible to reconstruct the standard type of deglaciation sequences which have been postulated elsewhere.

SURGING GLACIERS AND CONFORMABLE GLACIAL RESPONSE

Surging glaciers can have a number of impacts on the glacial deposits in a valley. Repeated surging can obliterate any morainal evidence for ice marginal positions. They can through ploughing action construct a moraine which is a combination of glacial events. They can superimpose push moraines on pre-existing moraines or other glacial forms. The Pleistocene and Holocene geomorphology of valleys subject to surging glacier activity will contrast dramatically with that of valleys without a history of surge occurrence. Further complication can arise if a glacier was not formerly subject to surging and has now developed this phenomena, or vice versa, a situation which for most locations it has been impossible to resolve in the field.

Examples of the above three scenarios can be quoted from the St. Elias Mountains (Fig. 3). Bighorn Creek Glacier (Fig. 4) has repeatedly destroyed moraines (Rutter, 1964) with the result that evidence of Holocene advances is difficult to interpret as distinct from surge events. The Holocene is therefore a zone of surging influence. The Klutlan Glacier has, through repeated surges, created a moraine sequence which can be placed in temporal sequence through study of the vegetative development on the form (Birks, 1980). The Donjek Glacier moraine has superimposed push moraines on pre-existing moraines of Holocene age (Fig. 5). This complex glacier deposit was interpreted



HG.3. Location map of southwest Yukon sites. Inset maps of models of glaciation of Gladstone Creek.

FIG.4. Aerial photograph of Kluane and Donjek Ranges southwest Yukon, with the surging Bighorn Glacier in the centre. Air Photograph A 15434 114 reproduced by permission of National Air Photo Library.

FIG.5. Donjek Glacier moraines. Recent surge push moraines dominate the proximal side of the main ridge.

by Denton and Stuiver (1966) as a Neoglacial moraine but the presence of denuded moraine surfaces on the distal side of the locations of their dated material indicates that a longer Holocene record is preserved.

In a fossil landscape the implications are that the same sequence of glacial events will not necessarily be represented in neighbouring valleys or regionally. The question also arises as to whether glaciers in the same area will all register the same responses to climatic events. In the St. Elias the changes in the accumulation and ablation regimes will need to be much greater on the St. Elias Icefield to produce terminus changes in glaciers such as the Donjek or Kaskawulsh in comparison to the smaller local ice caps in the Kluane and Donjek Ranges to the east of the main icefield. The small ice caps, more sensitive to mass balance changes, should produce a more detailed fluctuation record. The confusion in the interpretation of the Holocene from the early Hypsithermal/Neoglacial models to the multi fluctuation model of Denton and Karlen (1973, 1977) to the variable fluctuation model of Karlen (1979) is therefore quite understandable.

The currently glacierized areas of the St. Elias Mountains have the advantage for interpretation of the general conformity of the ice flow to the topography, radiating out from the ice cap along the major valley systems. By contrast the Ruby Range to the east of Kluane Lake was glaciated by regional ice flow unconformable to the existing topography.

THE RUBY RANGE

The glaciation of the Ruby Range, from a glaciological viewpoint, can be divided into four main phases; i) complete regional ice cover, ii) the waning of the complete ice cover, iii) regional ice extention up the major valleys of the range and iv) the occurrence of local ice, possibly interacting with iii. The glaciological conditions and their implications can be evaluated for each of these phases.

Complete regional ice cover

Ice entered the Ruby Range from the west (St. Elias Mountains source area) and from the east, (either deflected St. Elias Mountains ice or cordilleran ice) (Fig. 3). The probable confluence zone is along the east side of the range with the Aishihik and Sekulmun Lake basins filled with ice from the east or the south and the main part of the range covered by direct St. Elias ice. The term confluence might be too strong as the zone was probably one of merger of ice flows (Fig. 3) and there is no morphological evidence for any boundary condition.

During this situation the flow of the ice in the Ruby Range would be determined by the ice thickness in relation to the altitudinal range of the underlying topography. As the glaciated region boundary is hypothesised to lie just to the north of the area one can postulate that the thickness of the ice was not large compared to the topographical range and that the stress patterns within the ice, and thus the flow of the ice, would be dominated by topography with complex convergent and divergent stress conditions. The ice moving into the Ruby Range would initially conform to the valleys of Raft Creek, Gladstone Creek and Cultus Creek with overtopping of the plateau surface as ice build up in the Kluane Lake basin continued. The plateau surfaces lie at up to 2,200 m., 10 km. from Kluane Lake whose surface lies at about 900 m and the lake itself is of considerable depth. Thus the ice build up in the Shakwak Trench would have to be at least 1,500 m thick before the Ruby Plateau could be overtopped (Fig. 6). Ice build up in the Kluane Lake basin is therefore crucial to the glaciation of the Ruby Range. Ice with an elevation of over 2,200 m would also imply total coverage of the Donjek and Kluane Ranges on the east side of the St. Elias Mountains. The occurrence of this total coverage must have been early in the Pleistocene although no way of dating the event has been found so far. Modelling using ice sheet gradients has not been pursued because of the possibility that Pleistocene ice had different physical and chemical properties.

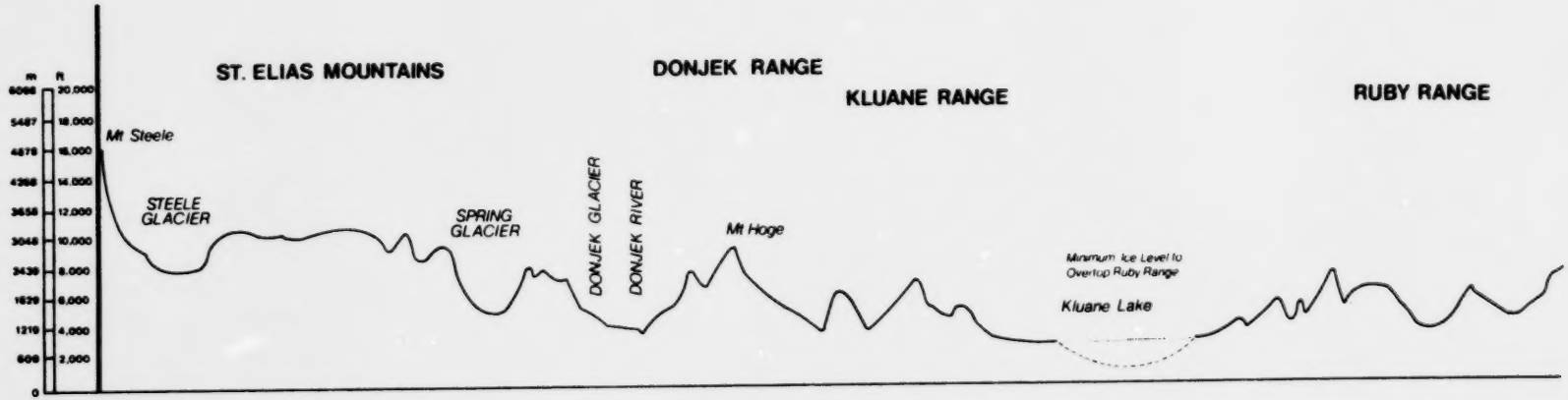


FIG.6. Cross section from the St.Elias Mts. to the Ruby Range. Southwest Yukon.

Waning of complete regional ice cover

At an early stage of the waning of the regional ice cover the plateau surfaces of the Ruby Range would become exposed. High level glacial meltwater channels above Gladstone Creek are now parts of the tributary valley systems in most cases but demonstrate that ice filled the valley when the surfaces of the plateau were already exposed to weathering activity. The degree and duration of weathering activity is demonstrated by the occurrence of tors, large fossil patterned ground systems, block streams and solifluction lobes.

Regional ice penetrating the major valleys

Moraines exist in Talbot Creek, Raft Creek, Rockslide Creek, and Gladstone Creek, from the penetration of the regional ice into the lower sections of the valleys. The ice tonques indicated by these moraines produced major dams to water drainage. A lake in Talbot Creek between the moraine and the mouth of Alaskite Creek was shallow and drained to the north through Tyrrell Creek. In this phase ice dams must have existed at the east and west ends of the Gladstone Creek system to explain the formation of a large lake in the valley. Strandlines for this lake exist at the Sekulman Lake end of the system and most of the valley bottom deposits have been modified by this lake. As the ice dominated in the Sekulmun basin it was no longer able to produce a barrier at the east end of the Gladstone system. The limit of the ice from the west within the Gladstone system at this time is difficult to hypothesise. Hughes (Personnal Communication) considers it to lie east of the present drainage divide close to the terraces which fill the eastern end of the system. The morphological evidence for this is very tenuous and the deposits are hypothesised by the author to be mass movement deposits off the south facing valley wall which, in this location, has exposures of heavily weathered bedrock on high angle slopes.

The penetration of the regional ice at this late state in conforming to the valley systems produced some interesting divergence patterns which can be illustrated by a scenario for the Raft Creek and Talbot Creek

systems. It has not been possible to verify this due to the problems of finding datable material and in order to be definitive about the Pleistocene history of the area it will be necessary to date almost every landform in the area.

Local ice conditions

With the decline of the influence of the regional ice it became possible for local ice centres to develope in the Ruby Range. To the north of the Gladstone Creek system these were cirque glaciers and there is no evidence, in the authors opinion, for local ice caps. Cirque glaciers occurred at the heads of a number of the creeks and particularly in the Raft Creek, Rockslide Creek and Talbot Creek systems. Moraines down valley from these cirques demonstrate that limited valley glaciers developed in some of the systems and that they may have been synchronous with late stages of upvalley regional ice conditions described above. Hughes proposes local ice accumulation in the topographic depression at location A (Fig. 3). This seems improbable in that the moraine to the east, which is some of his primary evidence, indicates only limited advance and a ice marginal position should be evidence in the valley to the west, tributary to Gladstone Creek, and there is no such formation in this valley. He proposes that the ice was confluent with regional ice flowing up Gladstone Creek and became deflected into this major flow. This would imply a large glacier and should show some indication of erosion at the unconformable junction with Gladstone Creek. In fact this site is more probably a divergence point for the regional ice flow with ice moving up the tributary valley not down it. A further difficulty with the Hughes model is explaining the formation over a topographic depression of a local ice cap which was sufficiently limited in size not to cover the area of tors at location B, Fig. 3 but was large enough to fill the valley C Fig. 3 and be confluent with ice in Gladstone Creek.

CONCLUSION

The primary conclusion and recommendation is that glaciological interpretations are a vital first step in any interpretation of the landscape

evolution. The attempts to infer glaciological conditions from a set of geomorphological data, which is only a limited set from the late phases of glaciation, have met with numerous problems. Attempts have been made to determine the glaciological conditions but these have often been based on erroneously simple symetry models, or ice conditions from totally dissimilar areas and in not accepting the probability fo different ice properties. By attempting to create glaciological conditions to fit the geomorphology we have arrived at a number of impossible situations given current knowledge of ice physics. The 'large basal ice stream' of Dyke et al. (1982) are a case in point.

It is obvious that glaciological responses of ice sheets and glaciers are variable even within small areas. This is most apparent where surging glaciers occur and where, therefore, neighbouring valleys have vastly different histories. The major questions which arise are, glaciers which surge at present have a surge character in the past, have glaciers which do not surge at present had a surge history in the past, and how can we identify in the fossil record whether surging occurred. I feel that many of the dichotomes which have appeared in detailed geomorphological work have been due to variations in glaciological response of which surging is the extreme. As we gain more information on the surge phenomena many of the answers to the geomorphological problems will emerge.

It is imperative that we do not continue to modify existing models on the basis of more detailed geomorphological studies but that we comprehend the overall glaciological conditions. It is significant that it is now accepted that the continental ice sheet was fluctuating in different ways at different times around the ice margins, advances and retreats cannot be correlated across North America and yet we still attempt to draw direct comparisons between Scandinavia and North America. Increasingly the possiblity of more glaciations is mentioned but this perpetuates the standard fluctuation model.

The glaciological questions must be answered first. What are the precise conditions at the glacier led where the bed morphology is highly

variable? What were the physical and chemical characteristics of the Continental Ice Sheet Ice? Do the differences indicated from the Devon Island site imply that glacial erosion and transport mechanisms were entirely different? These are critical questions because one set of answers would mean that all of our interpretations to date have serious flows.

The three field sites discussed in this paper illustrate the importance of producing a glaciology model first before trying to produce any geomorphological interpretations. In some cases more glaciological knowledge is required but there is more than sufficient information available to approach many geomorphological problems.

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